poisons, such as that of bubonic plague, and of some other poisons of a non-bacterial origin.

MESSRS. LONGMANS AND CO. have issued a new edition of Prof. Lloyd Morgan's "Animal Biology." The book was originally published twelve years ago to meet the requirements of the Intermediate Science and Preliminary Scientific Examinations of the London University. The present edition has been revised, and some chapters re-written, to meet the requirements of the existing syllabus. Several illustrations now appear in the work for the first time.

NEW editions of two well-known books of chemistry (Ostwald's "Grundriss der Allgemeinen Chemie," and Lothar Meyer's "Outlines of Theoretical Chemistry," the latter translated by Profs. Bedson and Williams) have recently come to us from their publishers—Engelmann of Leipzig, and Longmans and Co The former is a third edition, and the latter a second, and an attempt has been made in each case to bring the work up to date.

REFERENCES to practically every article and work on geography published during the year 1896 will be found in the fifth volume of the "Bibliotheca Geographica," prepared by Dr. Otto Baschin for the Berlin Geographical Society, and just published by the firm of W. H. Kühl. A comprehensive classification of subjects is adopted, and it is easy to find the works published in any branch of geography in 1896. In adtion, there is a complete index of authors. Students of geography know the work so well that no comment upon its thoroughness is necessary here.

THE additions to the Zoological Society's Gardens during the past week include a Green Monkey (*Cercopithecus callitrichus*) from West Africa, presented by Mr. G. P. Kinahan; a Macaque Monkey (*Macacus cynomolgus*) from India, presented by Mr. A. M. Burgess; a Gambian Pouched Rat (*Cricetomys gambianus*), a Nilotic Trionyx (*Trionyx truinguis*) from Sierra Leone, presented by Mr. Ernest E. Austen; a Red-footed Ground Squirrel (*Xerus erythropus*) from West Africa, presented by Mr. F. H. D. Negus; two Herring Gulls (*Larus argentatus*), British, presented by Mr. J. W. Edgar; a Melodious Jay Thrush (*Leucodioptron canorum*) from China, presented by Mrs. Currey; a Spoonbill (*Platalea leucorodia*), a Kestrel (*Tinnunculus alaudarius*), captured at sea, presented by Captain E. W. Burnett; a Green Turtle (*Chelone viridis*) from Ascension, presented by Mr. W. Hebden, C.E.; a Chameleon (*Chamaeleon vulgaris*) from North Africa, presented by Mr. F. G. Ward; two Serrated Terrapins (*Chrysemys scripta*) from North America, a Bennett's Cassowary (*Casuarius bennetti*) from New Britain, a White Goshawk (*Astur novae-hollandiae*), two Sacred Kingfishers (*Halcyon sancta*) from Australia, a Forsten's Lorikeet (*Trichoglossus forsteni*) from the Island of Sambawa, a Ring Ouzel (*Turdus torquatus*), British, deposited; a Crab-eating Raccoon (*Procyon cancrivorus*), two Short-eared Owls (*Asio brachyotus*) from South America, purchased.

OUR ASTRONOMICAL COLUMN.

HOLMES' COMET (1899 *d*).

Ephemeris for 12h. Greenwich Mean Time.

1899.	R.A. h. m. s.	Decl. ° ′ ″
Oct. 26	2 45 7·14	+49 11 29·7
27	43 55·55	13 2·6
28	42 43·32	14 12·0
29	41 30·56	14 58·0
30	40 17·40	15 20·5
31	39 3·95	15 19·6
Nov. 1	37 50·33	14 55·4
2	2 36 36·67	+49 14 8·0

NOVA SAGITTARII.—*Harvard College Observatory Circular*, No. 46, gives the details of the position of Nova Sagittarii, discovered in April 1898, as obtained from micrometric measurement of enlargements from the plates, taken with the 8-inch Bache and 11-inch Draper telescopes, on which the star was photographed. Prof. Pickering finds that the accuracy obtainable by this method is equal to that given by the best meridian circle observations. The mean position as determined is

$$\left.\begin{array}{l} \text{R.A.} = \text{18h. 56m. 12·83s.} \\ \text{Decl.} = -13^\circ\ 18'\ 12''\!\cdot\!98 \end{array}\right\} (1900).$$

ORBIT OF EROS.—In the *Astronomische Nachrichten* (Bd. 150, No. 3597), Herr Hans Osten, of Bremen, discusses the numerous observations of the new minor planet now available, and gives the two following provisional sets of elements for the orbit:—

Epoch of Nodal Passage, 1898 *Oct.* 1·0. *Berlin Mean Time.*

	I.		II.
	° ′ ″		° ′ ″
$M =$	238 38 33·627	...	238 39 44·636
$\omega =$	137 9 24·77	...	177 39 21·05
$\Omega =$	342 8 48·58	...	303 31 53·37
$i =$	30 42 32·105	...	10 49 33·99
$\phi =$	12 52 17·14	...	12 52 18·33
$\mu =$	2015″·57814	...	2015″·34326
$\log a =$	0·1637380		

STRASSBURG OBSERVATORY.—The annual publication compiled under the supervision of Herr E. Becker, the director of the Imperial Observatory of the University of Strassburg, has recently been issued, containing the reductions of star observations made during the period 1882–1888, together with miscellaneous results to 1893. The observations made with the meridian circle, occupying 154 pages, are preceded by some twenty pages giving details of the determination of collimation, level, azimuth and other corrections. Following these are given the individual observations of the positions of 223 stars measured from 1882–1883, and of 1146 stars measured during the period 1884–1888. From these three catalogues are compiled, one of 254, one of 858, and one of 368 stars, the latter containing corrections from Epoch 1880. Three appendices deal with heliometer measures of the partial solar eclipses of 1890, 1891 and 1893, the determination of the form the pivots of the meridian circle of the observatory, and the compilation of precession tables (both annual and secular) respectively.

THE NERVE-WAVE (LA VIBRATION NERVEUSE).[1]

AS you told us, sir, two days ago in your admirable address, the century now drawing to an end is most honoured in the close union of men of science of all nations. If, owing to stupid prejudices and barbaric hate, nations are still separated by divisions which may lead them into fratricidal war, it falls to the men of science at least to set the example of concord, in order that by their teaching, based on reason, they may bring to all peace, sweet peace—the chimæra of the past, the hope of us all to-day, the reality of to-morrow. To this end nothing can be more effective than the great example of the British Association and the Association Française, who, within the space of a few days, are to meet twice as partners in their fertile work: to-morrow on English soil, in this hospitable town of Dover; five days later on the soil of France, on the shores you can see from here, where you will find the same courteous and cordial welcome as our countrymen will receive on this side.

Yet after these words of peace must come words of war—nay, its open declaration. Men of science have not the right to stay within the closed gates of their tower of ivory; it behoves them also, even at the cost of vain popularity, to wrestle and to wrestle unceasingly for justice; to form a grand international league, to turn the united forces of all generous minds against the common foe, the worst enemy of man: and this is ignorance. We must not value unduly the admirable conquests won by science in this century. Admirable as they are, they are yet nothing as compared to the great mystery beyond. Newton compared our science to that of a child, who should pick up a pebble on the

[1] Evening Address delivered by Prof. Charles Richet on September 15, at the Dover Meeting of the British Association. Translated by Prof. Marcus Hartog.

sea shore, and think he has penetrated the secrets of ocean. After all our searchings and all our efforts, to-day we can hardly say more. The shades that surround us are as deep as in the time of Newton; and in this universe, vast and obscure, at most scattered glimmers of light, few and far between, reach our straining eyes.

We need all the co-operation of all men of science, of all nations, to dispel some of these shades. What madness it would be not to unite, not to walk hand in hand, but to strive apart! The reward of this union will be above all price: the conquest of truth, the control of brute matter, the gift of a life less precarious and less painful to man, feeble man.

And so you see what we should think of those self-styled patriots and nationalists, who speak of French science, English science, German science, as if science were not international, and lifted high above our vain frontier limits.

To the history of nerve-waves many workers of diverse countries have contributed their share; as with every great scientific problem, every country of the world has taken part in its solution. But before I go on, let me pray your indulgence for treating of so arid and so difficult a subject before you.

I.

The world around us presents itself in different aspects to the eyes of the student and of the layman. The layman sees external objects, endowed with properties apparently inherent in them, and commonly defined by the impressions made on our senses. A given object is warm, light, electrified, heavy, and so forth; and every one thinks that heat, light, electricity, weight, are so many realities, distinct from the object itself. But the man of science conceives matters otherwise. For him this vast universe is formed of an indefinite "something" termed "Energy," and he knows that this force may have different manifestations in motions of diverse kinds. We are almost justified in saying that "Energy is one"; that its aspects appear to our senses so different because the various movements of this energy have not all the same qualities. They differ in number, in frequency, in rapidity, in form; and according to these different modalities which we perceive, and to their results, we have heat, light, electricity, attraction.

The movements of this energy are all transmitted in the same way, by wave-motion—"undulation" or "vibration," as we call it; and the physicists, by wonderful research, in which the highest mathematics must be utilised, have succeeded in determining the forms of certain kinds of these waves. And even those motions of energy which we do not so well understand, we are justified, by what we do know, in regarding also as wave-motions or undulations.

I need not dwell on this phenomenon of undulation or vibration. We all know the simple case when a pebble is dropped into still water; and the surface, which was smooth as a mirror, now shows a series of disturbances propagated in ever-widening concentric circles. In each oscillation we see two periods: in the one the water recedes from the primitive plane of the mirror, in the other it comes back to it again. The former is the *period of departure*, the latter that of *return*.

So, if we hit a hanging weight, a pendulum, the shock at once removes it from its position of equilibrium, and it recedes further from it (period of departure); then it comes back again to its starting point (period of return). What I have called undulation and vibration are two names for the same phenomenon, of the greatest diversity in form, but essentually due to the wave-motion of a fluid. Though, if you will, this fluid, the ether, be of very hypothetical character, we will take it for granted here, and say that heat, light, electricity, gravitation, are all wave-motions of the ether.

Consequently, the outer world in its infinite diversity of aspect, in form and in colour, is the sum total of the various vibrations of force. These vibrations, most diverse in character and in intensity, act upon the living organism, and produce sensations therein. Now it is probable that, as I shall try to show you directly, these vibrations of the outer world only act on our senses by evoking within us another kind of vibration, to which are due sensation and perception. Thus the nerve-wave is revealed to us as the goal and the final term of the vibrations of the external world. Were there no nerve-wave, though, no doubt, all these external vibrations would still exist, still they could produce no effect on us. In virtue of its own proper vibrations, the living being becomes the microcosm, the recipient of the diverse vibrations of the macrocosm, the universe: by these vibrations only is the universe accessible to our understanding. Thus you see what of interest lies in the study of this nervous vibration, since through it the outer world is known to us, and through it we have the power to act on the outer world.

II.

This study is no new one; I should trespass beyond the limits of your courteous attention were I to try and recount all the classical facts that are well known at present. Yet, that you may understand the new facts I am coming to presently, I shall have to give you a short summary of some of these classical facts; and I hope that despite their being so well known, they will not be devoid of interest to you.

The nervous system is made up of distinct elements, each consisting of a cell, with very long fibrous outgrowths. These cells with part of their outgrowths are compacted into the central nervous system, while the rest of the outgrowths are produced into strands, the peripheral nerves. An elaborate microscopical analysis of the last few years, largely due to Golgi and to Ramon y Cajal, have shown that the total number of processes is countless. Each cell sends forth at least one outgrowth, the *axis cylinder*, which remains unbranched except at its very termination; while the others, like the branching roots of a forest tree, spread out in all directions, so that they interlace with those of its neighbours. Thus all the nerve-cells are in communication; the disturbance of one may affect all. And this disturbance may be propagated far and wide; for in the peripheral nerves pass out the axis-cylinders, which separate ultimately and get up to the very tips of the limbs, to the skin, the entrails, the muscles, and the glands. Think of the whole surface of the skin as provided with little nerve apparatuses, all capable of vibration and of transmitting their undulations through the sensory nerve-fibres to the nerve-centres; of the nerve-centres as possessing processes like the sensory fibres, whereby to transmit their orders to the muscular and glandular organs; and you will be able to realise the part played by the nerves in the life of the organism. It is a vast telegraphic apparatus, to receive, by its sensory receptive mechanism, all impressions from without, and to transmit, by its transmitting mechanism, corresponding messages to the organs of motion, the muscles. And, since all the nerve-cells are, moreover, in communication with one another, and since every living cell is in relation with nerves, we may sum up the relations of the living organism in this general formula: through the nervous system, any one living cell reverberates in every other cell, and is reverberated to by every other cell. Thus the living organism that possesses a nervous system is no mere aggregate of cells; it is an *individual*, all the parts of which co-operate for the common weal.

The nerve-cell, together with its prolongations, has received the name of "neuron"; we can conceive that by the inter-relations of all its neurons the living organism may be regarded as one gigantic neuron, sensible to all stimulations at the periphery, and answering them by stimulations of the motor apparatus, which are translated into acts of motion or of secretion. This sensibility and its motor response are linked by a phenomenon which we shall call for the present the "nerve-vibration" or "nerve-wave." How far is this name justified? This is the question that we have to deal with.

III.

Let us for the moment make the assumption (which is not quite exact) that the phenomena are identical in the peripheral nerves and in the central nervous centre, and that what applies to the one will also apply to the other.

We may, at least, accept them as analogous, since the axis-cylinder of the peripheral nerve is an expansion of the protoplasm of the nerve-cell. True, the reactions of the peripheral and of the central nerve tissue are not identical; but their differences are probably in accessories, not in essentials. We may, therefore, boldly accept their analogy, if not their identity; and we are justified in applying to the one the truth that we learn of the other.

The pace at which an impulse travels along a nerve is well known since 1850. Strange to say, just two years before, a great physiologist, one to whom the science is indebted for some of its grandest advances, Johannes Müller, declared that it was impossible for us to determine the speed of nervous transmission—an affirmation as imprudent as are all affirmations which proscribe formal conclusions to the science of the future.

Well, as I say, just two years after this unfortunate prophecy of Johannes Müller, Helmholtz ascertained that, if you determine the time of response by stimulating a nerve at a given point, you can determine the rate of transmission by stimulating the same nerve at a measured distance, say a decimetre, above that point; for, as in this case, the response will be delayed, the period of delay measures the rate the nerve impulse has taken to travel over ten centimetres. Since then countless determinations have been made of the speed of the nerve-current. It has been found to vary with the temperature and with the character of the nerve stimulated; it is less rapid in the nerve-centres than in the peripheral nerves, less in cold-blooded than in homœothermic (or so-called warm-blooded) animals. But it never differs much from thirty metres per second.

Moreover, this nerve current has been found to be always transmitted in both directions from the point of stimulation. I will not dwell on the exceedingly technical proof of this law, but merely recall the fact that whether the nerve stimulated be motor or sensory, the nerve current travels both ways along it, both towards the periphery (skin, muscle, &c., as the case may be) and towards the central nervous system.

A most important fact is that an electrical disturbance accompanies every stimulation of a nerve. If in the undisturbed condition we place the poles of a circuit with an interposed galvanometer at two points of a nerve (one on its surface, the other on a cut end), to ascertain its electric condition, we find that there is an electric tension between them, that there exists in the nerve a certain current. If we then stimulate the nerve, the current is seen to be reversed, or, as we say, undergoes a "negative variation," and the rate at which this change is transmitted is sensibly the same as that of the nerve-wave. Matteucci, Du Bois Reymond, Bernstein, Waller have studied all the complex details of this process; so that it now ranks among the best known phenomena in physiology.

We ask:—Are there, concurrent with this electric variation, modifications in the chemical and thermic condition of the nerve or nerve-centre? Yes, in all probability; but the answer is not certain. Schiff thought that by stimulating the retina of the pigeon he induced a change in the temperature of the brain. Mosso also thought he could find localised areas of higher temperature in the brain after stimulating certain points; but the elevation of temperature is, to say the least, of low intensity and difficult to determine.

In this rapid sketch, the last law I have to formulate is *the law of the integrity of the organ.* The physical and mechanical union may be maintained; but if its organic continuity be severed as by a cut, even when the two ends are joined up, the nerve-current is no longer transmitted.

IV.

Several hypotheses may be put forth as to the nature of this phenomenon.

Formerly, when words were accepted in place of facts, it was said that there was a transference of "animal spirits" (a conception due to Descartes); this was the current expression in the sixteenth, seventeenth and eighteenth centuries. A curious apparent confirmation was found in Richard Lower's experiment: he tied a nerve, and saw that it swelled above the seat of ligature; this, said he, was the accumulation of the animal spirit, arrested by the tightened thread. The experiment was a perfectly valid one; and you see that from it it was possible to deduce conclusions that were perfectly false. The swelling was due to the increase of blood pressure and to inflammation.

We may drop this old hypothesis of "animal spirits," and pass to four theories put forward to explain the nature of the nerve-current.

(1) *Mechanical Hypothesis.*—If, as is probable, the semi-fluid protoplasm of the nerve-cell and its prolongations form one continuous whole, it follows that a mechanical disturbance of this liquid mass will be propagated to a distance along the whole length. Suppose a capillary tube filled with mercury; a disturbance of the mercury will be propagated the length of the tube, so that at the far end we perceive a vibration started from the opposite end. In this case the nerve-wave would be the molecular disturbance of a liquid enclosed in a capillary tube.

This hypothesis would afford a fair explanation of the electrical phenomena involved; for we know that the friction of a fluid in a capillary tube produces electricity. However, this mechanical explanation presents certain difficulties, for in a capillary tube the narrower its calibre the more rapidly the vibration is damped; consequently, it is hard to conceive that a vibration could be transmitted so as to be appreciable at the far end of a tube one or two metres long. It is true that we can form no supposition as to the absolute measurement of such perturbation; and perhaps almost infinitesimally small forces are adequate.

On the other hand, the electric disturbance that accompanies the nerve-wave does not lose intensity as it travels: on the contrary, Pflüger and other physiologists declare that it grows like an avalanche. Hence, taking all considerations into account, the nerve-wave is a phenomenon other than a mechanical vibratory molecular disturbance of the semi-fluid protoplasm.

(2) *Chemical Hypothesis.*—The transmission of the nerve-wave along a nerve has been compared to the explosion of a train of powder, or of mixed gases in a tube; and this you know is transmitted relatively slowly, nay, very slowly if the tube be of capillary dimensions. If, say, an explosive mixture of oxygen and hydrogen be contained in a very narrow tube, and a flame or spark applied at one end, the combustion will not be instantaneous, but will pass as a wave along the tube, and that a very slow wave, if the tube be narrow.

What at first sight would give some plausibility to this hypothesis is the fact that a very feeble stimulus may call forth a very strong response. Take the amount of energy received by a surface of 1 sq. cm. from a candle 300 metres distant; it is 1/10,000 millions of the total light-giving energy of the candle, a quantity whose absolute value is in one sense a negligible quantity, but which is adequate to give a sensory stimulus to the retina. The retina must be supposed to contain a quantity of accumulated energy susceptible of explosive liberation, so that the amount freed would be far in excess of the energy of the stimulus.

But there is one very serious objection to this hypothesis; it demands that the explosive tissue should be reconstituted afresh immediately after each explosion. It is not easy to see how the moment after the explosion, in the hundredth of a second, the nervous substance could be reconstituted afresh. Though serious, the objection is not irrefutable, for we know too little of the speed or slowness of the chemical changes of the organism to use this as an argument against any theory whatever.

(3) *Electrolytic Hypothesis.*—Certain chemical changes are characterised by their allowing of an immediate reconstruction after their occurrence, such are the phenomena of electrolysis. When a current passes through a saline solution, it is believed that, as it passes along, the salt is decomposed from place to place, and immediately reconstituted as soon as the current has passed. The passage of the electrolytic current is sometimes exceedingly slow. There is nothing to prevent our accepting some such explanation of the nerve-wave; it has the advantage that it can be brought more or less into harmony with the chemical and the electrical hypothesis, and can indeed reconcile them.

(4) *Electric Hypothesis.*—This supposes that an electrical current passes along a peculiar form of conductor—the nerve. The chief objection that has been urged, in the extreme slowness of the nerve-wave—30 metres per second—as against 700 million metres, the alleged rate of electricity. But this omits to take account of the fact that electricity travels at this speed in good conductors only. Electricity passes along a conducting wire, ten thousand, a hundred thousand, times as fast as along a badly conducting tube; it is only reasonable to admit that the transport of electricity may be enormously retarded in a capillary tube filled with a very bad conductor. It has also been urged that, since different nerves can transmit very different sensations simultaneously to the different parts of the nervous system, there should be a blurring and confusion from the imperfect insulation of the tubes if it were electricity that they conducted.

"How, for instance," we are asked, "could nerve-cells of the cord and the brain communicate their electrical disturbances in narrowly localised groups with that extraordinary precision, without the neighbouring cells feeling the effect?"

We do not attach much weight to this objection because, in the first place, the axis cylinders have an insulating covering of myeline, as have also the cells of the brain; and again, in electric fishes, electric shocks one hundred thousand-fold as strong pass between certain organs without the rest being at all affected, so perfect is the insulation.

Thus the hypothesis that the nerve-wave is an electric phenomenon is fairly satisfactory, especially if we admit that it resembles electrolytic action.

Certainly we must allow for the unforeseen; we must recognise the possibility that, perchance at no very distant date, we may receive the formal demonstration of fundamental differences between electrical and nervous vibrations, and have to admit that the latter possess special characters which differentiate them from all known classes of vibrations.

V.

I now come to a different order of facts, on which I will speak more fully, for I have to deal with my own researches, some, indeed, as yet unpublished. These I carried on in collaboration with M. André Broca; they are, I think, of a character likely to shed light on some of the conditions of the nerve-wave. True, they tell us nothing of the actual nature of nerve-vibration; but they will allow us to deduce the form of the nerve-wave.

Our experiments were made on the nerve-centres, not on the peripheral nerves; as a matter of fact, we believe that the laws which we have discovered for the one will apply to the other, and Charpentier's recent and most ingenious researches confirm this assimilation.

We must go back to the very definition of a vibration. We have seen that it is a movement of oscillation, an object is removed from a position of equilibrium and comes back to it again. Such is a *simple oscillation;* in a *complete wave*, after returning to the position of equilibrium from the furthest point, it passes that position and only returns after a certain traverse in the opposite direction.

If we call the first simple oscillation from the position of equilibrium the *positive phase*, the second oscillation is regarded as the *negative phase* of the complete wave. Now the phenomenon is no simple one; the return to equilibrium is not

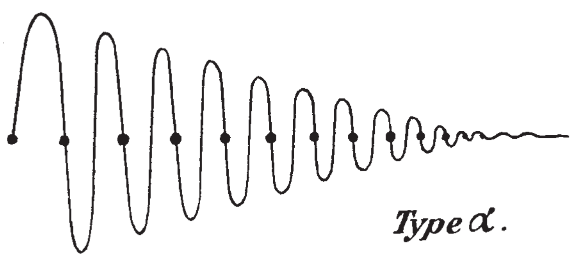

FIG. 1.

durable, and if no new condition intervene the vibration will continue. Were there no friction or resistance the vibration would persist indefinitely; for there is no reason for the motion to stop, and the pendulum, to take the very simplest case, would never return to rest at its original position of stable equilibrium. To stop the vibration there must be some deadening or *damping* process.

Physicists have studied the modes of damping, and find that they are divided into three types.

Type α is that of a pendulum, a vibrating string, or the waves of liquid when a stone enters the water. A series of complete waves follow with smaller and smaller oscillations, and the vibration dies out by the gradual decrease of the waves—secondary, tertiary, &c.—which followed the primary wave. This type of damping is, as we have said, due to the resistance of the medium consuming part of the energy; for, theoretically, a vibration once started would never stop. You are familiar with the fact that a pendulum continues to swing much longer in vacuo than in the air, and I need not dwell further on this point (Fig. 1).

Type β shows a very different character in its damping. After the pendulum has completed its first phase and passed the point of equilibrium, it meets a certain obstacle to its return point; it only swings back again very slowly thereto, and on reaching it it cannot pass beyond it. Indeed, from diverse theoretical considerations it may be proved that it never returns absolutely to the point of equilibrium; it approaches it indefinitely without ever reaching it; in short, ABA′ is an asymptotic curve of which AA′ is the asymptote. Later on we shall see what conclusions may be drawn from this as to the nature of the nerve-wave. Suffice it now to demonstrate the form of the wave with this type of damping. Practically, stable equilibrium is reached sooner than by type α: indeed, this is the type of damping used in the transmission of signals by submarine cables; where it is necessary to prevent each signal from producing a whole series of swings of the galvanometer needle, and to obtain as rapidly as possible its return to equilibrium and rest (Fig. 2).

Type γ remains to be described: here the pendulum, after being moved from the point of equilibrium, returns only very slowly to that position; this it does, for example, when hanging in a very dense medium. In this type of damping, as in β, there are no consecutive secondary and tertiary vibrations; nay, more, the damping is here so complete that there is no negative phase, only a simple oscillation. This curve is also asymptotic, and the return never reaches the primitive state of equilibrium (Fig. 3).

We see at once that the form of the wave is determined in each case by the type of its damping, and our experiments have

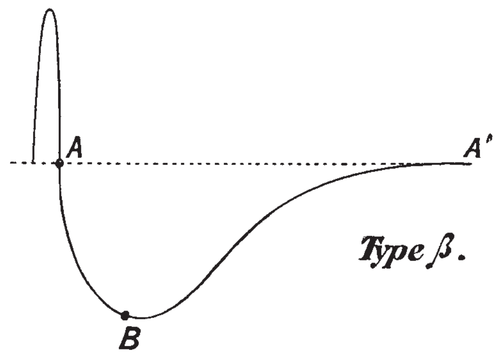

FIG. 2.

enabled us to determine the character of the damping of the nerve-wave. We might have set type α aside *à priori;* it would have been unreasonable to suppose it. If to wave 1 succeeded waves 2, 3, 4, &c., a single stimulus would produce a whole series of responses; now this is not the case with the nerve. Hence the damping must be on the type of β or of γ. But obvious as these considerations are when once stated, we did not reach them *à priori;* it required actual experience to enlighten us; so true is it that in science, at least in physiological science, experiment is more fertile than dialectic.

VI.

The following were the methods by which we determined the form of the nerve-wave. I will not describe our research in order of time; I shall only select some of the simplest, the most demonstrative, experiments. We know that but rarely are the earlier experiments one or the other; they are complex and

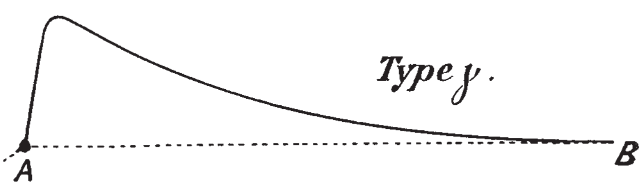

FIG. 3.

slow, and it is only by degrees that one learns how to simplify them and make them direct.

A dog is anæsthetised by the injection of a sufficient dose of chloralose into the veins (0·1 gramme to the kilo. of live weight), and electrodes are applied to the surface of its head. We can now observe the effects of an electric stimulus on the cerebral cortex under excellent conditions. The electrodes can be fixed immovably, so that the same part of the cortex is always stimulated; and the effects of the stimulus are always localised in the same muscles. If we repeat the same electric stimulus, supplied by a secondary current from accumulators, always of the same suitable intensity, we find that each successive electric shock, repeated at intervals of one second, calls forth a regular and equal muscular contraction in response. This regularity is complete, and if the conditions of circulation and respiration are kept satisfactory for one, two, or even three hours, we have a

series of regular contractions which are easy to register. But when we quicken up the succession of the stimuli, there comes a time when the responsive contractions lose their regularity: a normal contraction is followed by a small one, a large one by a small one, and so on. Thus we can determine at what rate of intermission of the successive stimulations their responses lose their regularity: we find that when the intervals between the induction shocks are less than the tenth of a second, at the normal temperature of the body (39° C. for the dog) the contractions are no longer regular. Matters now go on just as if, after the large normal contraction, there were a *refractory period*, during which the excitability of the nervous system is lowered.

Marey, in his beautiful researches on the heart, had previously showed that after a contraction of the heart there is a short refractory period during which it is not excitable. So, after the stimulation of the brain, a period not exceeding 1/10″ intervenes during which it is not excitable, a refractory period.

Whatever be the temperature of the animal under experiment, we always find this refractory period, which, however, becomes easier to measure when the temperature falls, for then it lengthens out enormously. It is 0·1″ at 39° C.; 0·18″ at 35° C.; and if we chill the dog greatly, to 30° C., it rises to 0·6″. Hence it is advantageous to chill warm-blooded animals for the purpose of these observations.

It is noteworthy that this refractory period can be demonstrated otherwise than by electrical stimuli; mechanical shocks will also serve the purpose. If we poison a dog with chloralose, it becomes extremely sensitive to every mechanical disturbance. The least jolt of the table on which it lies makes it start, and though insensible, and not susceptible to pain, it responds to every jolt by a start. We can register these starts; and if, working with a dog cooled to 30°, we repeat the jars at intervals of less than half a second, the starts lose their regularity. Under these conditions a big start is followed by a small one, and *vice versâ*, though the jolts of the table are quite equal. In successful experiments we may even find the second shock absent; so that if the times of the successive jolts be noted as a, a^1, a^2, a^3, a^4, &c., we only get responsive shocks at a, a^2, a^4, &c.

The physicists have given the mathematical and mechanical explanation of this phenomenon, which they call the "*synchronisation of the oscillators*"; it has recently formed the subject of an important memoir by Cornu, which, however, I cannot describe even in abstract here. Suffice it to say that these refractory intervals presuppose the existence of a refractory period, of a *negative phase* in the nerve-wave.

The synchronisation of the nervous oscillation with that of the stimulus can only be explained by the assumption of the vibration of an apparatus (the nervous apparatus) possessing a proper period of its own, and with which we regulate and adjust the proper period of a second apparatus (the stimulating apparatus).

Thus, by this method we have succeeded in determining the duration of the nerve-wave; and we may state that this is 1/10″, an exceedingly slow rate as compared with electric or luminous vibrations, whose period is measured in 1-one thousand millionths or billionths of 1″.

We can also determine the form of the wave, and we find it approximate to our type β. If we consider the period of 0·1″ which elapses between the stimulus and the completion of the nerve-wave, we find that it may be divided into two periods: (A) in the first part a second simulus will augment the effect; it is the "*phase of summation*" or *positive phase* of the wave. (B) in the second period the stimulus produces a decreased effect; this is the "*phase of subtraction*" or *negative phase*. Now the phase of summation is very small, scarcely more than 0·01″, while the phase of subtraction is very long, nearly 0·09″; but I must not go into more detail on this point, lest I should enter on matters too strictly technical, which I prefer to avoid.

VII.

In cold-blooded animals the phenomena are quite different; and recent experiments have shown us how imprudent it would have been to generalise too hastily. If, indeed, we repeat the experiment on a tortoise, we find results apparently contradictory of those I have just related to you. A stimulus following another always appears to produce a stronger response than its predecessor. *There is no refractory period, there is a summation phase all the time.* Of course I mean that the stimuli must not be too far apart; if the interval exceeds 2″, two successive stimulations of the brain call forth equal contractions. But with intervals of less than 2″ summation phenomena are always observed, the more marked as the interval between successive stimuli is decreased. Finally, as I say, there is no refractory period.

Hence we may conclude that in cold-blooded animals (at least in the tortoise) the nerve-wave has a different form from that of the dog; after the displacement from the primitive position of equilibrium there is only a slow and gradual return, without any such backward oscillation as explains the negative phase in the dog. This form of wave we have described under the third type of damping (type γ) (Fig. 3).

This type of wave is exceedingly slow; if the tortoise be chilled by the use of suitable stimuli, we can estimate its duration at 2″. But with normal animals at 15° C. the period may perhaps be taken as 1″.

This difference of tenfold is not surprising; there was no antecedent improbability in conceiving that the nervous phenomena of a tortoise are ten times as slow as those of a dog.

VIII.

The fact that the nerve-wave lasts one-tenth of a second in the dog, as it probably does approximately in man, opens up a field of interesting considerations which confirm the results of direct experimental physiological observation.

If the nerve-wave lasts 1/10″, it follows that two nerve-waves cannot remain completely dissociated when they follow at shorter intervals than this. Suppose that a stimulus of light calls forth a nervous reaction, a sensation; this reaction, this sensation, will last at least one-tenth of a second; and consequently when a fresh stimulus follows on the first, its sensory response will not be clearly distinct unless this interval at least separates the two. If they follow more closely, they will blend together. Well, a classical and well-known experiment tells us that we cannot receive more than ten or eleven distinct retinal sensations in a second. At eleven per second, we already experience *flickering*; that is, the images are becoming confused. This, the persistence of retinal images, is the familiar principle of the cinematoscope, which has latterly received such elegant popular applications on a large scale.

No such exact studies have been made on the confusion of acoustic or tactile stimuli. But the very remarkable and concordant results of retinal sensation are enough to prove that the cerebral vibration consequent on a stimulation of the retina has a period of 1/10″.

If we turn to the case of a voluntary movement, determined also by a cerebral nerve-wave, we find the same figure. Schäfer in 1886 determined that distinct successive muscular contractions, voluntary or called forth (as reflexes) by electrical stimuli, very rarely exceeded 11–12 per second. Herringham found a frequency of 9–12 in pathological tremors. In the case of shivering from cold, I have determined frequencies of 10, 11, 12, 13 per second. Griffiths determined a frequency of 10 for the muscles of the thumb, and 14 for those of the arm. The Swedish physiologist, Lovèn, found that the electric oscillations of the cord determined by very frequent stimuli were only 8–10 per second.

Yet we know that if muscles be stimulated directly by rapidly alternating currents, they will contract with much greater frequency. The numerous physiologists who have studied the subject are agreed that we may thus determine as many as thirty or forty muscular contractions per second If then we can only produce some ten voluntary contractions in the time, the cause lies, not in the muscles, but in the cerebral apparatus, which cannot vibrate more rapidly. Its period is 0·1″; it can only vibrate ten times in a second—can only order ten distinct voluntary movements of the same muscle in a second. It is not that the muscle cannot obey, but that the central nervous system cannot give its orders at a greater speed.

Now I will give you an experiment that you can all try for yourselves, which proves most clearly that the vibration of the nerve-centres determining a psychological phenomenon lasts about one-tenth of a second. When I thought over the various modes of obtaining a very rapid muscular motion, it occurred to me that perhaps the best was the articulation of some sentence pronounced with the greatest possible rapidity. We may admit that every syllable articulated represents a distinct muscular contraction, and consequently a distinct effort of the will. On trying what was the greatest speed of articulation, I found it

was eleven syllables a second; and, indeed, at this speed all the syllables were not perfectly articulated.

This experiment has no particular interest in itself, for it only confirms the results of Schäfer, Lovèn and Griffiths, that repeated voluntary muscular actions have a speed of some ten or twelve per second. But, if we modify it slightly, its bearings are much wider. If instead of *vocally* articulating the syllables, we *think* them and articulate them only *mentally*, we exclude muscular action from any share in the process, and the rapidity of the mental articulation will be the index of the cerebral rhythm, not the muscular. Well, I found, as any of you can do with the help of a good seconds watch, that the mental articulation gives exactly the same figure as the vocal; that is, ten or eleven syllables per second.

We come to the interesting and relatively unforeseen conclusion that the cerebral phenomena of feeling (in the retina), volition (on the muscles), and thought (in mental articulation) cannot be repeated faster than twelve per second, and that they last about one-eleventh, or in round numbers one-tenth, of a second; the isolated sensation, the isolated act of will, the isolated intellectual process, have all the same minimum duration.

Placing this result next to our determination of the period of the nerve-wave, we conclude that there is here more than a mere coincidence; it is an *à posteriori* proof of our hypothesis as to the period of the nerve-wave.

From the psychological point of view this leads us to very important deductions. Of course we can conceive the second to be divided into hundredths, millionths, billionths; but these divisions have no relation to our direct consciousness. Our consciousness can only perceive much longer intervals. Our cerebral organisation determines narrow limits for our appreciation of time. We may therefore define the *psychological unit of time*, the irreducible unit, as *that minimum duration of time which is appreciable to our intelligence*. This is, indeed, susceptible of further theoretical subdivision; but such subdivisions correspond to no real mental image.

We may say, in other words, that the minimum time which our consciousness can directly apprehend is, in round numbers, one-tenth of a second.

"Swift as thought" is an everyday phrase; but you see thought is not very swift, after all, if we compare it to the enormous frequency of the vibrations of light and electricity.

Sir William Crookes, one of your most illustrious presidents, spoke of the relativity of our knowledge in his recent address; he alluded to the cruel imperfections of our animal nature. For us there exists no time-interval shorter than one-tenth of a second; and yet during this short interval, within which our gross intellectual apparatus cannot penetrate, who knows what sequences of phenomena may go on, which we could perceive if our nervous system had a shorter period of vibration? Then would phenomena which we perceive as continuous reveal their true character of discontinuity; those molecular vibrations which to us do not appear as vibrations would take on their real aspects. In a word, our time-unit, which is so different from the units of many phenomena of matter, makes us live in one perpetual illusion.

One more point I wish to touch upon is interesting in many respects. Let us come back to the diagram I gave you above to show the mode of damping of the nerve-wave. I told you that the original level is never regained when the system is damped to a position of rest; it approaches the level indefinitely but never reaches it. Practically speaking, equilibrium is reached at the end of the tenth of a second; physically and physiologically speaking, everything is set in order; the nerve-wave is ended, and the return to equilibrium is total. But if we deal with infinitesimal quantities this return is not complete; so that if we imagine an apparatus capable of appreciating infinitesimal quantities, it would show that, as the mathematical theory predicts, the return to equilibrium is never complete or absolute.

Well! we may fairly suppose that consciousness is alive to this infinitely small quantity, and that the impossibility of the complete return to the primitive equilibrium accounts for the strange phenomenon, unknown in the inorganic world, which we call *Memory*.

After a nerve-wave, the neuron is no longer in the same state as before; it retains the memory of the wave, and this makes it now other than what it was. I pronounce the vowel "A"; one-tenth of a second later I can pronounce some other vowel, for my nervous system has returned to equilibrium; but this return, however, is not complete, for the memory of the "A" which I pronounced persists, and will persist indefinitely. The primitive condition will never recur, whatever happens. In time the memory of the vowel "A" will gradually fade, but it will never be effaced. A nerve-wave of the brain is never completely extinguished.

The fact is that we are here on the confines of two totally distinct worlds: the world of physics and the world of psychology. What is infinitesimally small in the physical world may possibly be infinitely great in the psychological world. The residues of nerve-waves, the asymptotic prolongations of curves, may be neglected by the physiologist and the physicist; they are not negligible to consciousness.

Consciousness distinguishes them from the strong vibrations actually going on, which it recognises as "the present"; but the waves that are passed still exist for consciousness, never perhaps to be annihilated.

Assuredly this is but an hypothesis, perhaps an analogy, a comparison, rather than an hypothesis; but it is none the less interesting to note how far the physiological theory of the damping of the nerve-wave is in agreement with the grand psychological fact of memory, which it is scarcely possible to explain in any other way.

IX.

Thus the nerve-wave in its form and period, and in the mode of its damping, is comparable with the various waves of the unbounded universe in which we live, move and have our being. But this resemblance must not lead us away from the recognition of the abyss that separates the nerve-wave from all the other phenomena within our reach. The vibrations of the forces scattered about us are—at least with the greatest probability—blind phenomena, which know not themselves, which are the slaves of irresistible fatality. The nerve-wave, on the contrary, knows and judges itself; it is self-knowing or self-conscious; it can distinguish itself from the world which surrounds it and shakes it.

Since it possesses intelligence—for intelligence and consciousness are synonymous terms—it is susceptible of perfectibility; it is capable of right reasoning and of wrong reasoning; it can attain a moral ideal forbidden to those brute forces which follow their fated course; it can conceive the idea of truth and justice when it is a question of defending the innocent, of establishing brotherhood among men.

Consciousness, intelligence, the making for higher perfection—these are characters that have nought in common with the characters of other waves; they seem to be phenomena of another, a higher order. This vibration, whose physical conditions we have studied, enters into the domain of morals; and this fact establishes its essential difference from all other vibrations.

Assuredly the prodigiously rapid and regular undulations of light, and of electricity, appeal right justly to our admiration; but nothing is so admirable as this disturbance of the nerve-cell, which is self-knowing, self-judging, self-transforming, which strives to amend itself, and which from the stimuli which strike it can deduce some of the laws ruling the vast universe distinct from it. The nerve-wave of man—himself the last result of evolution—is the most perfect term of the things and of the beings which it is given to us to know.

Vast as is the world, mighty as are the fires of the infinite stars, the intelligence of man is of a higher order than these; and I would fain exclaim with the great philosopher, Immanuel Kant: "More than the starry heaven above my head, one thing fills me with admiration: the moral law in the heart of man."

ZOOLOGY AT THE BRITISH ASSOCIATION.

ON the opening day (Thursday) only the President's address was taken, and the Section then adjourned with the object of hearing addresses in other Sections which were of biological interest. The total number of papers brought before the Section this year was not as large as usual, but they extended over a wide range of zoological subject-matter, as the following outline programme shows:—

Friday morning, morphological papers; Friday afternoon, papers on entomology and mimicry; Saturday, marine biology; Monday, morphology, &c.; Tuesday, papers on sea-fishery questions. The usual reports upon investigations in progress were also submitted.